JTWC's

72-HOUR FORECAST ERRORS

Sun, Oct 2, 1988

Capt John D. Pickle
Draft #1

1. Introduction:

   The ~~JTWC's~~ average forecast error from 1967 to 1987 (excluding 1977 due to a missing data set) is 368 nm with a 239 nm standard deviation. The median values were not calculated as in Tsui and Miller (1986) based on their results which showed little difference between the two values. The average error for HPAC from 1979 (the first year of operational use) until 1987 is 347 nm with a standard deviation of 223 nm. From 1979 until 1987, OTCM accumulated an average error of 341 nm with a 204 nm standard error. CSUM, operational since 1985, has an average error of 312 nm with one standard deviation of 194 nm. From these basic results and from many of the conclusions from Tsui and Miller's work, these three aids provide the best guidance of all objective aids. Here is where the touchy part comes in: guidance versus performance. This study is different from Tsui and Miller's and most others because it tries to study the guidance of the aids provided and JTWC's response during specific forecast scenarios and not clumped into large, operationally unusable blobs of data.

2. Overall Performance:

   2.1. Intensity:

   Tsui and Miller (1986) stated that based on the performance of the objective aids of tropical storm-, typhoon- and super typhoon-intensity systems (these classifications are based upon the maximum intensity attained during the tropical cyclone's lifetime), that OTCM performed better on more mature systems based upon the initialization of the model with a "mature"-type vortex. However, this is a misleading conclusion as well as operationally ~~unusable~~. When the best track intensity corresponding to the time of the forecast is considered, the lowest errors occur in the 0 to 30 kt category for JTWC, HPAC and OTCM (Table 1). One word of caution on the performance of CSUM: there are roughly 1/3 the number of cases compared to OTCM and 1/4 the size of HPAC's database.

Table 1

Intensity (kt)	JTWC	HPAC	OTCM	CSUM
0-30 kts	348	328	309	279
35-60	373	346	351	265
65-200	368	352	336	348
~~0-200~~ all	368	347	341	312

# of posits? Sample size

2.2. Latitude:

Based upon graphs of the performance of the aids and JTWC with respect to month of the year and latitude of the forecast position, it is evident that forecasting is more difficult with increasing latitude (see insert #1). For JTWC, the mean forecast errors greater than 400 nm (the 400 nm border will be considered the boundary for large errors) begin around 12 degrees north in January through May, expanding northward to 22 degrees in September and decreasing to 12 degrees by November. Due to the large frequency of tropical cyclones in August, September and October, the yearly distribution shows the 400 nm boundary beginning north of 14 degrees. HPAC and OTCM have similar boundary fluctuations throughout the year.

JTWC, HPAC and OTCM (CSUM not considered due to the limited number of data points) have a consistent area of accurate forecasts (< 300 nm) in the lower latitudes which persist for several or more months. HPAC does very well during the month of September as does JTWC and OTCM.

2.3. Longitude:

None of the objective aids show significant trends of low or high forecast errors with respect to longitude of the forecast position and the month of occurrence; however, there is a small ridge of higher errors migrating from roughly 148 degrees east during July to 138-140 degrees by June the next year. There are not a large number of data points involved, usually 20 to 40 per 2 degree increment, but it is an interesting feature.

2.4. Overall Movement Classification and Intensity:

JTWC and the objective aids "make their money" on

MONTHLY DISTRIBUTION OF MEAN FORECAST ERRORS AND LATITUDE

JTWC

	LT	TYPE	J-M	JUN ~~MAY~~	JUL ~~JUN~~	AUG ~~JUL~~	SEP ~~AUG~~	OCT ~~SEP~~	NOV ~~OCT~~	DEC ~~NOV~~	TOTAL ~~DEC~~	
1	1-2	JM	0	0	0	0	0	0	0	0	0	
2	3-4	JM	382	0	0	0	0	262	454	406	366	
3	5-6	JM	295	0	180	0	0	199	409	185	300	
4	7-8	JM	365	514	230	225	244	311	263	275	322	
5	9-10	JM	356	397	329	267	267	277	283	296	310	
6	11-12	JM	402	344	299	420	303	265	295	320	319	A
7	13-14	JM	368	327	338	387	308	321	421	548	361	
8	15-16	JM	559	371	373	388	316	401	590	859	405	
9	17-18	JM	513	632	311	339	358	454	555	0	387	
10	19-20	JM	523	459	331	375	374	560	644	0	402	
11	21-22	JM	521	492	405	438	377	666	1011	0	435	
12	23-24	JM	0	290	499	412	415	613	683	0	443	
13	25-26	JM	0	0	601	446	414	788	0	0	474	
14	27-28	JM	0	0	479	432	458	0	0	0	456	
15	29-30	JM	0	0	188	260	0	482	0	0	318	n = 8
16	31-32	JM	0	0	0	0	0	0	0	0	0	
17	33-34	JM	0	0	0	0	0	0	0	0	0	
18	35-36	JM	0	0	0	0	0	0	0	0	0	
19	37-38	JM	0	0	0	0	0	0	0	0	0	
20	39-40	JM	0	0	0	0	0	0	0	0	0	

H[illegible]C

LT x 2

	LT	TYPE	J-M ~~J-A~~	JUN ~~MAY~~	JUL ~~JUN~~	AUG ~~JUL~~	SEP ~~AUG~~	OCT ~~SEP~~	NOV ~~OCT~~	DEC ~~NOV~~	TOTAL ~~DEC~~
1	1	JM	0	0	0	0	0	0	0	0	0
2	2	JM	323	0	0	0	0	296	564	402	409
3	3	JM	450	0	0	0	0	352	350	264	386
4	4	JM	321	512	278	233	231	338	241	250	289
5	5	JM	312	459	291	280	192	262	344	239	284
6	6	JM	406	854	357	384	243	243	390	334	325
7	7	JM	424	389	326	360	259	326	436	388	348
8	8	JM	391	424	337	399	264	396	385	669	363
9	9	JM	0	406	392	279	305	383	601	0	342
10	10	JM	110	366	495	320	377	578	680	0	398
11	11	JM	0	710	524	373	342	420	0	0	417
12	12	JM	0	0	412	402	378	0	0	0	402
13	13	JM	0	0	789	355	372	0	0	0	421
14	14	JM	0	0	434	332	0	0	0	0	364
15	15	JM	0	0	177	0	0	0	0	0	344
16	16	JM	0	0	0	0	0	0	0	0	0
17	17	JM	0	0	0	0	0	0	0	0	0
18	18	JM	0	0	0	0	0	0	0	0	0
19	19	JM	0	0	0	0	0	0	0	0	0
20	20	JM	0	0	0	0	0	0	0	0	0

MONTHLY DISTRIBUTION OF MEAN FORECAST ERRORS AND LATITU

O7CCL

CTX2

	LT	TYPE	~~J-A~~ JM	~~MAY~~ JUN	~~JUN~~ JUL	~~JUL~~ AUG	~~AUG~~ SEP	~~SEP~~ OCT	~~OCT~~ NOV	~~NOV~~ DEC	~~DEC~~ TOT
1	1	JM	0	0	0	0	0	0	0	0	0
2	2	JM	362	0	0	0	0	0	394	0	382
3	3	JM	403	0	0	0	0	177	340	281	348
4	4	JM	370	730	0	276	187	178	318	235	325
5	5	JM	496	406	374	259	183	338	228	284	308
6	6	JM	446	0	238	447	260	277	265	294	302
7	7	JM	607	218	296	339	322	304	325	345	322
8	8	JM	878	427	356	327	267	361	343	706	348
9	9	JM	0	790	370	380	329	361	542	0	366
10	10	JM	128	575	403	317	368	528	452	0	369
11	11	JM	0	690	286	320	289	0	0	0	346
12	12	JM	0	0	325	427	372	0	0	0	387
13	13	JM	0	0	442	500	558	0	0	0	500
14	14	JM	0	0	178	502	0	0	0	0	356
15	15	JM	0	0	50	0	0	0	0	0	50
16	16	JM	0	0	0	0	0	0	0	0	0
17	17	JM	0	0	0	0	0	0	0	0	0
18	18	JM	0	0	0	0	0	0	0	0	0
19	19	JM	0	0	0	0	0	0	0	0	0
20	20	JM	0	0	0	0	0	0	0	0	0

O5CCL

CTX2

	LT	TYPE	~~J-A~~ JM	~~MAY~~ JUN	~~JUN~~ JUL	~~JUL~~ AUG	~~AUG~~ SEP	~~SEP~~ OCT	~~OCT~~ NOV	~~NOV~~ DEC	~~DEC~~ TOT
1	1	JM	0	0	0	0	0	0	0	0	0
2	2	JM	0	0	0	0	0	0	0	0	0
3	3	JM	0	0	0	0	0	0	0	0	0
4	4	JM	0	0	0	0	0	0	264	0	264
5	5	JM	682	0	309	192	64	319	199	227	245
6	6	JM	896	418	369	262	192	218	219	399	286
7	7	JM	0	671	316	229	235	231	373	310	296
8	8	JM	0	568	230	357	230	374	0	519	306
9	9	JM	0	0	372	224	302	389	0	0	327
10	10	JM	131	0	340	369	319	567	0	0	359
11	11	JM	0	0	426	328	209	0	0	0	305
12	12	JM	0	0	662	636	442	0	0	0	579
13	13	JM	0	0	751	523	492	0	0	0	569
14	14	JM	0	0	0	0	0	0	0	0	559
15	15	JM	0	0	0	0	0	0	0	0	0
16	16	JM	0	0	0	0	0	0	0	0	0
17	17	JM	0	0	0	0	0	0	0	0	0
18	18	JM	0	0	0	0	0	0	0	0	0
19	19	JM	0	0	0	0	0	0	0	0	0
20	20	JM	0	0	0	0	0	0	0	0	0

only 26 cases total

LONGITUDINAL DISTRIBUTION

JTMC

LG x 2 + 100

	LG	TYPE	~~J-A~~ J-M	~~MAY~~ JUN	~~JUN~~ JUL	~~JUL~~ AUG	~~AUG~~ SEP	~~SEP~~ OCT	~~OCT~~ NOV	~~NOV~~ DEC	~~DEC~~ TOT
1	1	JM	0	0	0	0	0	0	0	0	0
2	2	JM	0	0	0	0	0	0	0	0	0
3	3	JM	0	0	0	0	0	0	0	0	0
4	4	JM	0	0	0	0	0	0	0	0	0
5	5	JM	0	0	0	0	0	0	551	0	507
6	6	JM	790	243	400	297	158	0	437	222	338
7	7	JM	822	0	213	292	235	247	422	136	265
8	8	JM	326	188	418	255	276	366	324	62	320
9	9	JM	445	302	222	602	273	282	202	129	338
10	10	JM	356	522	226	392	318	309	322	397	349
11	11	JM	410	361	309	302	225	289	382	290	319
12	12	JM	235	448	335	427	254	356	368	237	338
13	13	JM	351	361	358	406	247	406	414	241	353
14	14	JM	408	362	342	419	328	542	348	277	396
15	15	JM	365	271	292	356	321	431	532	403	369
16	16	JM	330	542	328	369	305	375	390	438	369
17	17	JM	319	456	279	245	296	283	424	293	309
18	18	JM	222	356	333	337	358	340	335	359	332
19	19	JM	379	481	348	298	339	327	312	574	351
20	20	JM	435	518	370	328	343	321	422	816	400
21	21	JM	492	289	396	370	404	404	342	476	398
22	22	JM	394	372	359	499	403	434	352	266	412
23	23	JM	325	0	473	411	379	349	365	278	383
24	24	JM	302	0	449	442	344	271	565	273	390
25	25	JM	320	0	381	324	346	353	300	227	342
26	26	JM	273	0	510	544	376	327	312	210	367
27	27	JM	440	0	508	459	372	402	366	251	421
28	28	JM	552	604	485	520	558	359	403	251	506
29	29	JM	412	0	446	225	569	510	359	233	428
30	30	JM	529	0	348	579	561	322	276	346	439
31	31	JM	581	0	317	490	419	234	212	206	417
32	32	JM	494	0	387	449	471	446	241	142	430
33	33	JM	273	0	318	453	216	384	212	210	305
34	34	JM	489	0	261	446	0	220	268	370	389
35	35	JM	0	0	0	388	367	292	213	313	328
36	36	JM	0	0	0	580	495	298	244	0	427
37	37	JM	0	0	0	0	618	274	295	0	450
38	38	JM	375	0	0	568	385	0	237	0	404
39	39	JM	66	0	0	0	0	0	0	0	226
40	40	JM	0	0	0	0	298	0	0	0	383

HMAC

LG x 2 + 100

	LG	TYPE	~~J-A~~ J-M	~~MAY~~ JUN	~~JUN~~ JUL	~~JUL~~ AUG	~~AUG~~ SEP	~~SEP~~ OCT	~~OCT~~ NOV	~~NOV~~ DEC	~~DEC~~ TOT
1	1	JM	0	0	0	0	0	0	0	0	0
2	2	JM	0	0	0	0	0	0	0	0	0
3	3	JM	0	0	0	0	0	0	0	0	0
4	4	JM	0	0	0	0	0	0	0	0	0
5	5	JM	0	0	0	0	0	0	560	0	510
6	6	JM	0	352	0	311	130	0	307	0	261
7	7	JM	0	0	0	315	177	268	0	394	263
8	8	JM	251	0	0	202	213	170	427	0	218
9	9	JM	161	0	150	370	267	295	227	0	334
10	10	JM	121	202	0	411	315	318	420	0	338
11	11	JM	224	595	377	238	215	342	483	303	316
12	12	JM	478	638	443	380	254	325	329	151	346
13	13	JM	387	671	490	435	206	325	302	300	349
14	14	JM	234	481	411	327	174	573	279	453	354
15	15	JM	218	378	303	298	224	469	372	277	309
16	16	JM	311	418	505	316	328	256	400	366	355
17	17	JM	435	503	309	232	324	319	444	271	329
18	18	JM	346	423	258	422	358	325	323	326	343
19	19	JM	284	574	318	262	323	363	313	498	333
20	20	JM	367	518	431	334	329	348	241	543	361
21	21	JM	309	243	335	371	306	406	364	342	345
22	22	JM	360	0	361	421	329	443	377	150	381
23	23	JM	457	0	384	200	228	311	389	134	300
24	24	JM	355	0	301	347	114	239	612	221	313
25	25	JM	265	0	450	284	256	357	425	250	342
26	26	JM	428	0	439	696	342	346	559	204	423
27	27	JM	575	0	636	480	343	404	351	174	427
28	28	JM	543	0	390	438	450	0	659	291	473
29	29	JM	435	0	344	234	377	0	599	257	[illegible]
30	30	JM	393	0	282	345	431	0	373	373	369
31	31	JM	522	0	0	342	473	0	332	192	422
32	32	JM	907	0	416	327	426	0	292	139	453
33	33	JM	657	0	0	448	118	0	147	194	341
34	34	JM	0	0	0	394	0	0	186	0	334
35	35	JM	0	0	0	374	580	0	151	0	435
36	36	JM	0	0	0	0	625	0	25	0	520
37	37	JM	0	0	0	0	400	0	0	0	324
38	38	JM	0	0	0	258	322	0	0	0	279
39	39	JM	0	0	0	0	0	0	0	0	0
40	40	JM	0	0	0	0	0	0	0	0	0

LONGITUDINAL DISTRIBUTION

07CM

CG x 2 + 100

	LG	TYPE	J-M ~~J-A~~	JUN ~~MAY~~	JUL ~~JUN~~	AUG ~~JUL~~	SEP ~~AUG~~	OCT ~~SEP~~	NOV ~~OCT~~	DEC ~~NOV~~	TOT ~~DEC~~
1	1	JM	0	0	0	0	0	0	0	0	0
2	2	JM	0	0	0	0	0	0	0	0	0
3	3	JM	0	0	0	0	0	0	0	0	0
4	4	JM	0	0	0	0	0	0	0	0	0
5	5	JM	0	0	0	0	0	0	639	0	584
6	6	JM	0	0	0	476	224	0	342	0	338
7	7	JM	0	0	0	469	314	391	0	268	377
8	8	JM	466	0	0	304	228	229	283	0	267
9	9	JM	252	0	295	445	255	274	171	0	308
10	10	JM	172	738	0	324	432	355	241	0	346
11	11	JM	468	866	278	287	330	369	418	247	354
12	12	JM	558	716	344	385	286	419	402	194	378
13	13	JM	321	687	336	295	247	375	366	133	325
14	14	JM	285	410	267	324	308	574	237	268	339
15	15	JM	479	452	339	320	288	280	289	311	328
16	16	JM	347	452	351	335	306	338	237	360	329
17	17	JM	136	233	305	212	201	453	328	0	287
18	18	JM	294	0	240	221	237	337	308	474	283
19	19	JM	590	730	297	258	266	371	234	535	346
20	20	JM	351	0	330	503	379	289	264	499	381
21	21	JM	509	285	255	473	218	281	243	0	345
22	22	JM	334	0	303	325	254	301	143	351	296
23	23	JM	250	0	301	207	251	258	242	447	268
24	24	JM	276	0	219	369	225	220	200	352	261
25	25	JM	462	0	359	286	143	308	266	215	319
26	26	JM	0	0	479	922	124	251	245	172	337
27	27	JM	753	0	617	504	315	0	241	204	397
28	28	JM	819	0	466	466	539	0	324	0	495
29	29	JM	825	0	0	254	484	0	302	274	338
30	30	JM	742	0	367	0	473	0	330	402	459
31	31	JM	0	0	0	659	407	0	312	317	397
32	32	JM	0	0	0	0	351	0	0	187	416
33	33	JM	0	0	0	0	252	0	0	0	383
34	34	JM	0	0	0	432	0	0	298	0	372
35	35	JM	0	0	0	413	497	0	154	0	405
36	36	JM	0	0	0	511	524	0	0	0	482
37	37	JM	0	0	0	0	435	0	0	0	410
38	38	JM	0	0	0	552	241	0	0	0	524
39	39	JM	0	0	0	0	0	0	0	0	304
40	40	JM	0	0	0	0	206	0	0	0	337

C3CM

C3 x 2 + 100

	LG	TYPE	JM ~~J-A~~	JUN ~~MAY~~	JUL ~~JUN~~	AUG ~~JUL~~	SEP ~~AUG~~	OCT ~~SEP~~	NOV ~~OCT~~	DEC ~~NOV~~	TOT ~~DEC~~
1	1	JM	0	0	0	0	0	0	0	0	0
2	2	JM	0	0	0	0	0	0	0	0	0
3	3	JM	0	0	0	0	0	0	0	0	0
4	4	JM	0	0	0	0	0	0	0	0	0
5	5	JM	0	0	0	0	0	0	0	0	435
6	6	JM	0	0	0	309	217	0	182	0	246
7	7	JM	0	0	0	314	0	254	0	0	294
8	8	JM	0	0	0	244	0	394	294	0	317
9	9	JM	0	0	0	259	0	328	190	0	301
10	10	JM	131	0	0	269	572	254	235	0	315
11	11	JM	0	0	254	407	538	258	206	323	321
12	12	JM	0	0	302	529	309	294	402	185	362
13	13	JM	0	1050	402	431	252	367	246	0	363
14	14	JM	0	0	377	284	134	280	350	0	332
15	15	JM	0	550	287	264	140	0	280	388	286
16	16	JM	0	439	510	316	202	118	248	264	372
17	17	JM	0	551	258	248	125	303	0	0	320
18	18	JM	0	391	213	283	353	293	210	387	311
19	19	JM	0	0	285	144	228	574	0	503	292
20	20	JM	0	0	278	212	258	400	0	524	296
21	21	JM	0	0	259	390	166	474	0	254	303
22	22	JM	0	0	299	369	202	524	0	293	350
23	23	JM	0	0	284	0	164	266	0	231	217
24	24	JM	0	0	390	259	60	234	0	211	249
25	25	JM	0	0	276	0	86	216	0	206	199
26	26	JM	0	0	0	712	95	195	0	204	270
27	27	JM	896	0	0	488	392	0	67	0	399
28	28	JM	537	0	370	227	410	0	0	0	331
29	29	JM	0	0	0	0	223	0	0	326	244
30	30	JM	0	0	0	0	262	0	0	492	363
31	31	JM	0	0	0	0	147	0	0	0	204
32	32	JM	0	0	286	0	82	0	0	0	184
33	33	JM	0	0	0	0	139	0	0	0	168
34	34	JM	0	0	0	0	0	0	0	0	0
35	35	JM	0	0	0	0	0	0	0	0	0
36	36	JM	0	0	0	0	0	0	0	0	0
37	37	JM	0	0	0	0	0	0	0	0	0
38	38	JM	0	0	0	0	0	0	0	0	0
39	39	JM	0	0	0	0	0	0	0	0	0
40	40	JM	0	0	0	0	0	0	0	0	0

(Table 2)

straight-runners, especially JTWC and HPAC. Both have average forecast errors less than 300 nm for all intensity categories. Interestingly, OTCM does not outperform JTWC or HPAC in this category. When the along-track errors and the cross-track errors are considered for straight-runners, the majority of the errors for the weaker systems are dependent upon cross-track errors and the errors for more intense system are dependent upon the along-track errors.

The mean forecast errors increase for recurvers and other-type movers. The average JTWC errors for recurvers are greater than 400 nm. For HPAC and CSUM, the lowest errors are within the weakest intensity systems and get progressively worse with increasing intensity. OTCM's errors were not dependent upon intensity. Cross-track and along track errors are not studied due the the effect of the rotating best track tangent plane during recurvature.

Other-type movers have a similar error distribution as the recurvers: larger errors are associated with more intense tropical cyclones.

Table 2:

STRAIGHT-RUNNER

Mean Forecast Errors:

Intensity:	JTWC	HPAC	OTCM	CSUM
0-30 kts	248	286	276	229
35-60 kts	289	285	321	243
65-200 kts	280	266	314	300
~~0-200 kts~~ all	281	277	315	275

Mean Along-Track Errors

0-30 kts	-39	-85	-102	-94
35-60 kts	-86	-127	-89	-107

65-200 kts	-89	-119	-48	-147

Mean Cross-Track Errors

0-30 kts	81	142	102	185
35-60 kts	52	56	55	81
65-200 kts	65	90	136	123

RECURVERS:

Mean Forecast Errors

0-30 kts	410	364	286	322
35-60 kts	387	373	347	271
65-200 kts	414	384	330	368
~~0-200 kts~~ all	403	378	333	330

OTHERS:

Mean Forecast Errors

0-30 kts	385	327	389	272
35-60 kts	451	374	389	288
65-200 kts	386	379	372	381
~~0-200 kts~~ all	416	373	381	330

2.5. Distribution of Forecast Errors > 400 nm (Table 8)

JTWC has the highest percentage of forecast greater than 400 nm with 37% (note that this figure is based on almost twice as many forecasts as HPAC and nearly three times that of OTCM due to the data record). Interestingly, over one quarter of the time either HPAC or OTCM will be less than 300 nm in error for the JTWC forecast of > 400 nm, but over one half of the time either of the

aids will be greater than 400 nm also. When considered together, HPAC, OTCM and CSUM will be less than 400 nm 15% of the time (23% if only HPAC and OTCM are considered) and 24% of the time all the aids will be greater than 400 nm along with JTWC's forecast. Similar trends are observed when the forecast errors greater than 400 nm for the objective aids are studied. Roughly 1/4 to 1/3 of the time individual aids are significantly less than the inaccurate forecast.

Table 3:

JTWC Forecast Errors > 400 nm

Average : 616 nm
Stand Dev: 203 nm
Frequency: 1788
% of Total: 37%

Of Corresponding Forecasts, % of Aids That Were:	HPAC	OTCM	CSUM
<= 300 nm	26	27	33
300-350 nm	9	10	9
350-400 nm	8	8	10
>400 nm	57	55	47

3. Recurvature:

3.1. Overall Performance:

JTWC's 72-hour forecast errors are consistently over 400 nm from 2 days before recurvature until recurvature (Table 4). First, consider the timing of the errors: 72-hour forecasts issued 2 days before recurvature means that the verification point is one day after recurvature. JTWC's 72-hour errors 3 days before recurvature are lower because the verifying point of the forecast is near the recurvature point, or, in other words, the forecast track can still appear as a straight-runner yet verify "accurately" because there hasn't been the significant eastward movement to increase the error. The errors increase as the eventual recurvature nears due to the forecast verifying during east-component movement.

The guidance of the 3 statistically best aids, HPAC, OTCM and CSUM, are not very impressive either during this event. All the aids have errors greater than 400 nm from 2 days before recurvature (Figure 2). Notice that OTCM is better than JTWC's forecasts. It is rather intuitive why HPAC is not a helpful aid during recurvature because recurvature is not climatologically fixed by latitude and longitude and persistence is still indicating westward movement prior to recurvature. CSUM, although utilizing the ridge axis from analyses and prognostic fields, does not provide adequate guidance during recurvature, possibly due to inadequate positioning of the ridge or using the wrong mid-level surface for that particular tropical cyclone. CSUM rapidly looses utility during a recurvature scenario. OTCM, the dynamical model, does better, but does not provide adequate guidance to improve JTWC's forecasting ability during recurvature.

Due to the overall poor performance two days prior up to recurvature, the distribution of the > 400 nm errors and the number of errors involved with recurvature were compared in order to determine the rough percentage recurvature plays in the yearly errors of JTWC and the errors. Roughly 28% of all JTWC's errors greater than 400 nm are from recurvature; for HPAC and OTCM, 31% and CSUM, 40%. OTCM ?

The most difficult period to forecast is from one day before recurvature until recurvature. A significant part of the error is the timing of significant acceleration or not. Rapid acceleration and rapid movement to the northeast will be examined in a following section. A second factor in the error exists because the tropical cyclone is moving almost 180 degrees from a straight-runner forecast.

Many of the forecast error techniques cannot be utilized during recurvature to study for systematic errors because the errors use the tangent of the verifying best track as their reference plane. Because the tangent plane is rapidly changing during recurvature, the along track and cross track errors are misleading. In order to determine if the aids or JTWC has a systematic bias during the recurvature forecast, two types of errors will be examined in a later project (after we receive the data from NEPRF). These errors are north/south error and east/west errors. Simple in concept but practical. If the aid or JTWC forecast a straight-runner during recurvature, the dominant error will be west and most likely south. A dominant west error would also result if rapid northeastward acceleration occurred but

was not forecast. If rapid acceleration was forecast but did not verify, a significant east error would result.

A second reason for north/south and east/west errors are that the forecast aids appear (not yet verified statistically) to have a northward bias prior to recurvature, so that even if a straight-runner was forecast, the recurving best track would cross the forecast track at some point, thereby minimizing the errors. By examining the way the aids "beat" JTWC but do not provide adequate forecast guidance is as important as documenting systematic biases.

Table 4:

Mean Forecast Errors Associated with Recurvature

Hours Prior to Recurvature:	JTWC	HPAC	OTCM	CSUM
78-54	349	326	294	281
48-30	467	483	391	495
42-0	547	651	447	626

Errors when JTWC, HPAC and OTCM Available:

78-54	363	325	298
48-30	440	464	384
24-0	469	603	438

3.2. Intensity considerations: (Table 5)

Mean forecast errors for JTWC, HPAC and OTCM (too few points to study CSUM by intensity) with respect to intensity at recurvature and timing of recurvature are similar to the errors with respect only to timing: all forecasts are worse as the point of recurvature nears. OTCM shows an overall improvement of the forecast as the intensity at recurvature increases. To help the forecasters, this would usually correspond to OTCM's performance increasing with the intensity of the tropical cyclone being greater at the forecast time, probably a strong tropical storm or a weak typhoon intensity system.

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Abby-type

Table 5:

Mean Forecast Errors With Respect to Intensity of the Tropical Cyclone at the Point of Recurvature:

72-54 hours Prior to Recurvature:

Intensity	JTWC	HPAC	OTCM
35-60 kts	372	343	348
65-90 kts	327	299	278
95-140 kts	362	323	259

larger sample?

Intensity | Ridge
less
average
more

48-30 hours Prior to Recurvature:

Intensity	JTWC	HPAC	OTCM
35-60 kts	469	468	425
65-90 kts	451	433	356
90-140 kts	490	517	420

24-0 hours Prior to Recurvature:

Intensity	JTWC	HPAC	OTCM
35-60 kts	605	658	528
65-90 kts	486	652	443
95-140 kts	610	696	356

3.3. Width of recurvature/Number of False Starts:

The width of recurvature is estimated by the number of possible recurvature points that occurred prior to the last recurvature point. Recurvature points were defined as the point where the movement 6 hours prior were northward or north with a westward component and the following 6 hours were northward or north with an eastward component. The number of points of possible recurvature were counted for each track. This number could also be considered as the number of false starts of recurvature.

(table 6)

JTWC errors were higher for the forecasts issued 78-54 hours prior to recurvature if there were multiple recurvature points, which should be expected since the false starts would be misleading. HPAC performs consistently better if there are several false starts prior to recurvature, possibly due to the inclusion of a more northward persistence track being blended with the climatology. OTCM performs extremely well for 1 and 2 points of recurvature when forecasting 3 days before recurvature.

Overall, JTWC has the worst accuracy for systems that display only one or two recurvature points and improves as the bend of recurvature is broader or the number of false starts increases. This is true also for HPAC since a westward persistence is not included during broad recurvature. OTCM is the only aid that performs worse during broader recurvers and better during one-point events.

sharper (more narrow) peaks and 0 errors does better.

Table 6:

Mean Forecast Error and the Number of Defined Recurvature Points

78-75 hours Prior to Recurvature: 54?

Number of Points:	JTWC	HPAC	CSUM
1:	334	339	296
2:	318	307	193
3:	424	352	353
4-8:	366	306	350

48-30 hours Prior to Recurvature:

Number of Points:	JTWC	HPAC	CSUM
1:	449	547	417
2:	514	512	312
3:	399	400	372
4-8:	449	305	528

24-0 hours Prior to Recurvature:

	JTWC	HPAC	CSUM
1:	553	756	413
2:	569	766	526
3:	545	458	411
4-8:	460	320	425

3.4. Rapid Movement after recurvature:

JTWC had large forecast errors for tropical cyclones that (Table 7) experienced rapid movement with an eastward component. All of these systems were classified either as a recurver or an other (which could still be have recurved but some portion of the track was significantly erratic to be classified as an other). HPAC did not forecast this event well either. OTCM did significantly better than HPAC or JTWC but the mean error was still greater than 400 nm.

Table 7:

Mean Forecast Errors for Rapidly Moving Tropical Cyclones
- Eastward Component
- Forecast Errors Verified During ~~Speeding Event~~ Rapid motion (> 15 kts)

JTWC	HPAC	OTCM	CSUM
523	547	404	578

Corresponding Forecasts

JTWC	HPAC	OTCM
483	518	404

3.4.2. Intensity of Initial Point of the Event: (Table 8)

JTWC experienced large forecast errors for all three intensity categories; however, HPAC improved with increasing intensity. OTCM had significantly lower errors for weaker typhoon intensity systems, but the errors increased for both the stronger and weaker cases.

Table 8:

Mean Forecast Errors For Rapidly Moving Tropical Cyclones
- Eastward Component
- Forecast Errors Verified During Speeding Event (>15 kts)
- Intensity of Tropical Cyclone at Initial Point of Speeding Event

Intensity	JTWC	HPAC	OTCM
35-60 kts	533	602	438
65-90 kts	488	472	344
95-130 kts	600	421	442

3.4.3. Latitude of Initial Point of the Event:

JTWC and HPAC experienced lower forecast errors (Table 9) north of 25 degrees whereas, OTCM did slightly better south of 20 degrees. Both results are against the overall latitudinal trend that the aids do better at lower latitudes. The higher frequency of lower latitude tropical cyclones that were forecast well (i.e. straight-runners or recurvers more than 2 days before recurvature) decreased the overall average errors at lower latitudes.

Table 9:

Mean Forecast Errors For Rapidly Moving Tropical Cyclones
- Eastward Component
- Forecast Errors Verified During rapid motion ~~Speeding Event~~ (>15 kts)
- Latitude of initial Point of the Speeding Event

Latitude (N)	JTWC	HPAC	OTCM
0-20	565	621	391
20-25	626	483	441
25-40	435	456	407

3.4.4. Month:

JTWC improved (Table 10) during the August-September time frame however the errors were still significantly above 400 nm. HPAC

showed steady improvement throughout the season, but its errors were also significantly greater than 400 nm throughout the year. OTCM did poorly before August, but the errors during the rest of the year were near JTWC's overall yearly average.

Table 10:
Mean Forecast Errors For Rapidly Moving Tropical Cyclones
- Eastward Component
- Forecast Errors Verified During ~~Speeding Event~~ rapid motion (>15 kts)
- Month of Speeding Event

Month	JTWC	HPAC	OTCM
JAN-MAY	557	559	515
JUN-JUL	485	583	435
AUG-SEP	482	575	357
OCT-DEC	562	470	373

3.4.5. Recurver vs Other-Type Mover

Surprisingly, JTWC, HPAC and OTCM performed better on other-type movers compared to recurvers. (Table 11) This may be due to tropical cyclones moving on a more northward course prior to recurvature.

Table 11:
Mean Forecast Errors For Rapidly Moving Tropical Cyclones
- Eastward Component
- Forecast Errors Verified During Speeding Event (>15 kts)

	JTWC	HPAC	OTCM
Recurver	533	553	408
Other-Type	476	525	395

3.4.6. Time Difference Between Forecast and Initial Point of Speeding Event

The time difference between the forecast and the initial point of the speeding event is similar to the categories of time before recurvature; if the difference was between 72-54 hours, the

error was included 0 to 18 hours of rapid east-component movement. If the time difference was less than 0, then the forecast was issued when the tropical cyclone had been moving rapidly eastward. The additional information gained here is the duration of the speeding event. If the time difference is 48 hours, then the speeding event lasted at least 24 hours.

(Table 12) JTWC's errors gradually increased up to the time difference of 0 hours, which indicates that speeding was not forecast or was underforecast, and the errors increased because the speeding event contributed more to the verification error with decreasing time difference. When the time difference was less than 0, JTWC's errors decreased significantly but were still large.

HPAC showed inconsistent trends; performing best when the speeding event contributed little to the verification error. OTCM did significantly better best 0 to 24 hours prior to the beginning of the event, which may indicate that recurvature has already occurred and the speed forecast was the most important. This conclusion is somewhat confused by the increasing errors for forecasts issued after speeding had already begun.

Table 12:
Mean Forecast Errors For Rapidly Moving Tropical Cyclones
- Eastward Component
- Forecast Errors Verified During Speeding Event (>15 kts)
- Time Difference Between Forecast and Initial Point of Speeding Event

Time Diff	JTWC	HPAC	OTCM
72-54 hrs	435	384	404
48-30 hrs	603	668	474
24-0 hrs	775	558	264
< 0 hrs	549	634	404

3.5. Size considerations:

Unfortunately, this category has not been studied yet because we are still trying to acquire information of past tropical cyclones. Due to the information about beta drift and the BAM technique, this

study will provide useful information for TDOs in the future.

4. Rapid movement with a westward component:

There are two basic ways to view the time frame of the errors: either as verifying during a particular type of event or being forecast from the event. Both are important for operational forecasting: the first can be observed when the aids are plotted out prior to the forecast and the latter can be observed from the working best track. The forecast from rapidly moving east-component tropical cyclones was not studied because the chance for verification of these forecast was limited since most systems are weakening rapidly during this time. However, speeders with a westward component are often still early in their development and so verification is more likely. Similar reasoning follows for tropical cyclones that have stalled.

4.1. Verification:

Table 13

JTWC did extremely well overall, especially for speeders in with north and west components of movement. Systems that moved with a south component were not forecast as well; however, their frequencies are much fewer than those with a north component. HPAC performed similarly to JTWC. OTCM did outstanding for all west component speeder, regardless of north or south components of movement. CSUM also did very well for systems that tracked rapidly westward.

Table 13:

Mean Forecast Errors For Rapidly Moving Tropical Cyclones
- Westward Component
- Forecast Errors Verified During Speeding Event (>15 kts)

Average Direction:	JTWC	HPAC	OTCM	CSUM
180-360	318	335	301	297
180-270	397	449	303	
270-360	316	333	301	

4.1.2. Intensity at Initial Point of Speeding Event:

JTWC and HPAC displayed erratic trends when the intensities of the initial point of the speeding event are considered. JTWC

Table 14

performed best when the speeding occurred at low typhoon intensity and HPAC performed best when the tropical cyclone was either weak or very intense. OTCM showed significant improvement as the intensity increased. The errors for very intense tropical cyclones that sped westward was near 200 nm.

Table 14:
Mean Forecast Errors For Rapidly Moving Tropical Cyclones
- Westward Component
- Forecast Errors Verified During Speeding Event (>15 kts)
- Intensity at Initial Point of Speeding Event:

Intensity	JTWC	HPAC	OTCM
35-60 kts	325	317	358
65-90 kts	304	391	275
95-200 kts	366	313	206

(Table 15)

4.1.3. Time Difference Between Forecast and Initial Point of Speeding Event:
Only OTCM improved as the speeding event neared the forecast time, which holds with the rule of thumb that OTCM provides the best speed guidance during the forecast.

Table 15:
Mean Forecast Errors For Rapidly Moving Tropical Cyclones
- Westward Component
- Forecast Errors Verified During Speeding Event (>15 kts)
- Time Difference Between Forecast and Initial Point of Speeding Event

Time Diff	JTWC	HPAC	OTCM
72-54 hrs	342	357	358
48-30 hrs	426	386	246
24-0 hrs	408	509	248
< 0 hrs	311		

4.2. Forecast:

Not completed at this time.

5. Stalling:

Stalling was defined as speeds of movement less than or equal to 4 knots. One aspect that can be studied later is stalling occurring due to binary interaction with another tropical cyclone.

5.1. Verification:

Overall, JTWC and HPAC verify very well during stalling events, (Table 16) regardless of the average direction of movement. JTWC does best at east component stallers; whereas, HPAC and OTCM perform better for westward moving systems. CSUM does extremely well for the limited cases forecast for.

~~5.1.1.~~ Table 16:

Mean Forecast Errors For Stalled Tropical Cyclones
- Forecast Errors Verified During Stalling Event (< 5 kts)

	JTWC	HPAC	OTCM	CSUM
	324	296	376	229
Eastward Component	290	343	632	
Westward Component	331	289	341	

5.1.2. Intensity at the Initial Point of the Stalling Event: (Table 17)

In all three cases, JTWC, HPAC and OTCM perform best for stallers with initial intensities between 65 and 90 knots. The more and less intense tropical cyclones are not forecast as well.

Table 17:

Mean Forecast Errors For Stalled Tropical Cyclones
- Forecast Errors Verified During Stalling Event (< 5 kts)
- Intensity at the Initial Point of the Stalling Event

Intensity	JTWC	HPAC	OTCM
35-60 kts	341	326	402

65-90 kts	249	227	336
95-200 kts	368	372	378

(Table 18)

5.1.3. Latitude of the Initial Point of the Stalling Event:

JTWC and HPAC perform best in the lower latitudes for stallers and OTCM do best between 15 and 20 degrees. HPAC provides the best overall performance for all latitudes.

Table 18:

Mean Forecast Errors For Stalled Tropical Cyclones
- Forecast Errors Verified During Stalling Event (< 5 kts)
- Latitude of the Initial Point of the Stalling Event

Latitude	JTWC	HPAC	OTCM
0-15	250	276	327
15-20	324	269	295
20-30	398	327	475

5.1.4. Time Difference Between Forecast and Initial Point of the Stalling Event: (Table 19)

JTWC and HPAC do well roughly three days prior to the stalling event, and errors for JTWC, HPAC and OTCM increase roughly 1 day before the stalling event begins.

Table 19:

Mean Forecast Errors For Stalled Tropical Cyclones
- Forecast Errors Verified During Stalling Event (< 5 kts)
- Time Difference between Forecast and Initial Point of the Stalling Event:

Time Diff	JTWC	HPAC	OTCM
72-54 hrs	308	286	386
48-30 hrs	364	265	303
24-0 hrs	375	372	408

(Table 20)

5.1.5. Month:

Surprisingly, JTWC and HPAC perform best on stallers early and late in the year, and OTCM does best during the main typhoon season in the western North Pacific.

Table 20:

Mean Forecast Errors For Stalled Tropical Cyclones
- Forecast Errors Verified During Stalling Event (< 5 kts)
- Month of the Stalling Event

Month	JTWC	HPAC	OTCM
JAN-MAY	201	213	564 ?
JUN-JUL	453	358	
AUG-SEP	414	398	323 ?
OCT-DEC	284	258	

(Table 21)

5.1.6. Overall Type of Track: Recurver, Straight-Runner or Other:

In all cases, stallers that occur with other-type movers have the largest errors compared to stallers of straight-runners and recurvers. And, in all cases, stallers that occur with recurvers have low forecast errors. HPAC and JTWC are the best performers for stallers associated with straight-runners.

Table 21:

Mean Forecast Errors For Stalled Tropical Cyclones
- Forecast Errors Verified During Stalling Event (< 5 kts)

	JTWC	HPAC	OTCM
Straight-Runner	319	262	378
Recurver	296	308	284
Other	394	345	453

5.2. Forecast from a Stalling Event:

Mean forecast errors for JTWC and HPAC increase when forecasting from a stalling event compared to verification of a forecast

stalling event. Conversely, the errors for OTCM decreased. In all three cases, the average direction of the stalling event was not significant to the forecast error.

Table 22:

Mean Forecast Errors For Stalled Tropical Cyclones
- Forecast Errors Forecast During Stalling Event (< 5 kts)

	JTWC	HPAC	OTCM	CSUM
	362	345	332	277
Eastward Component	397	328	315	
Westward Component	355	348	335	

5.2.2. Intensity at the Initial Point of the Stalling Event: (Table 20)

The errors for OTCM increased significantly for all intensity categories compared to the overall errors. This would indicate that OTCM does extremely well on tropical depressions. HPAC does very well on intense tropical cyclones whereas JTWC and OTCM perform poorly. JTWC does best on tropical storm intensity systems.

Table 23:

Mean Forecast Errors For Stalled Tropical Cyclones
- Forecast Errors Forecast During Stalling Event (< 5 kts)
- Intensity at the Initial Point of the Stalling Event

Intensity	JTWC	HPAC	OTCM
35-60 kts	361	348	355
65-90 kts	444	405	353
95-200 kts	413	271	418

5.2.3. Latitude of the Initial Point of the Stalling Event:

JTWC does best at low latitudes whereas the two aids perform very well between 15 and 20 degrees. All three perform worse north of 20 degrees; however, OTCM is still less than JTWC's

overall average.

Table 24:

Mean Forecast Errors For Stalled Tropical Cyclones
- Forecast Errors Forecast During Stalling Event (< 5 kts)
- Latitude of the Initial Point of the Stalling Event

Latitude	JTWC	HPAC	OTCM
0-15	330	349	352
15-20	380	304	298
20-30	382	386	340

(Table 25)

5.2.4. Time Difference Between Forecast and Initial Point of the Stalling Event:

In this case, the time difference now indicates how long the stalling event has already been evident before the forecast is issued. The 0-24 hours category means that the stalling has been present for up to one day before the forecast was issued. JTWC performed best when the stalling event lasted for several days prior to the forecast and HPAC performed best during the early development of the event.

Table 25:

Mean Forecast Errors For Stalled Tropical Cyclones
- Forecast Errors Forecast During Stalling Event (< 5 kts)
- Time Difference between Forecast and Initial Point of the Stalling Event:

Time Diff	JTWC	HPAC	OTCM
72-54 hrs	224	403	?
48-30 hrs	296	346	284
24-0 hrs	390	338	361

(Table 26)

5.2.5. Month:

JTWC, HPAC and OTCM show the rough trend of poo performance early in the year with overall improvement during the latter portion of the year.

Table 26:

Mean Forecast Errors For Stalled Tropical Cyclones
- Forecast Errors Forecast During Stalling Event (< 5 kts)
- Month of the Stalling Event

Month	JTWC	HPAC	OTCM
JAN-MAY	381	306	446
JUN-JUL	404	552	354
AUG-SEP	372	313	330
OCT-DEC	310	342	297

(Table 27)

5.2.6. Overall Type of Track: Recurver, Straight-Runner or Other:

Stallers that occur during a straight-runners lifetime are forecast best; whereas the recurvers and other-type movers are not forecast as well.

Table 27:

Mean Forecast Errors For Stalled Tropical Cyclones
- Forecast Errors Forecast During Stalling Event (< 5 kts)

	JTWC	HPAC	OTCM
Straight-Runner	273	340	213
Recurver	364	335	340
Other	388	353	357